Integrating Multiple Stakeholder Interests into Conceptual Design

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Abstract: The engineering design process transforms stakeholder needs into design specifications. This study focuses on the engineering design process for systems of products and services known as product-service systems (PSS) and proposes a novel way to analyze PSS ideas by four characteristics: customer perceived value level, connectivity number, type and degree of connectivity, and configuration type. The process to apply this characterization scheme examines the inter-dependencies within a PSS and between the PSS and its environment and holistically incorporates the interests of customers, end-users, and social and environmental stakeholders early in the development process. This process clarifies design specifications in seven cases across five industries.

Introduction

Why is it important to incorporate multiple stakeholder interests in the engineering design stage of a new development process? The engineering design process, defined as the early stage of a new product or service development process, transforms stakeholder needs and desires to design specifications. During the new product/service development process, companies exploit and combine available technologies and realize the value of these technologies by systematically converting them into marketable products and services (Gregory, 1995), while at the same time making decisions that impact how much value customers can generate from these new products or services. How to best manage the new product/service development process has been an important topic among engineering management scholars and practitioners. This article intends to contribute to the topic of new product/service development processes from the perspective of how multiple stakeholder interests can be integrated into the engineering design of a product-service system (PSS).

A product-service system (PSS) is a set of products and services developed to jointly fulfill a user's need (Goedkoop, van Halen, te Riele, & Rommens, 1999). To enhance the value of a product or service to its multiple stakeholder groups from end-customers and users to society and the environment (Baines et al., 2007; Mont, 2002; Pigosso & Mcaloone, 2016; Waage, 2007), engineering designers must find ways to incorporate all stakeholder interests and then transform the interests to clear design specifications. Design specifications includes three aspects: required product and service features, stakeholder involvement, and contingent environmental conditions.

This article proposes a product-service system characterization scheme that comprises four characteristics: customer perceived value level, connectivity number, type and degree of connectivity, and PSS configuration type and presents a procedure to apply this characterization scheme. The procedure takes a PSS idea as the input, analyzes for its four characteristics in the characterization scheme, and outputs more clarity about this new PSS, helping development team members to produce a clearer design specification. The developed PSS characterization scheme has its theoretical basis in the theory of technical systems (Hubka & Eder, 1988) and is heavily influenced by well-established concepts in engineering and technology management that have been proposed to improve new product development lead time, manufacturability, and life-cycle cost including total quality management (Akao, 1990) and design for X (Maskell, 1991; Warwick Manufacturing Group, 2007).

The developed characterization scheme is developed from case studies involving twenty-five new products, services, and PSSs in the healthcare industry. The healthcare industry in this study includes manufacturers and providers of healthcare equipment and devices, software, healthcare professional services, physical fitness services, and mental health services. The characterization scheme is applied using the developed procedure in five industries including defense, healthcare, environmental protection, financial investment, and executive education, and the characterization scheme is found effective in improving the clarity of design specifications. This application procedure has the potential to be further developed as a practical tool for businesses to incorporate multiple stakeholder needs into the new product/service development process.

The investigated research topic is multidisciplinary, and different fields may have different interpretations of the same terminology. In order to better communicate the results of this study, the next section presents the definitions for terms used in new product/service development, PSS, sustainability, and stakeholder management. This section is then followed by a review of literature relevant to the engineering design process, new PSS development models and tools and their capability to incorporate multiple stakeholder interests, and system structural representations. The research methodology utilized in this study is then presented. The data collected and analyses utilized in the PSS characterization scheme are summarized in the findings section. The study's contributions to academia and the implications for engineering managers are presented, and the article concludes with the limitations of the study and the next steps.

Definitions

This section presents the definitions for terms used in new product/service development, PSS, sustainability, and stakeholder management as used in this study.

Insert Exhibit 1 here

Literature Review

In this section, the definition of the engineering design process is first presented, followed by a review of new PSS development process models and tools and their capabilities to incorporate multiple stakeholder interests. Then a review of system structural representations is presented, examining how the relationships between product and service elements are represented for engineering design. This section concludes discussing the need for a holistic approach for PSS engineering design that incorporates multiple stakeholder' interests.

Engineering design process

The engineering design process can be classified as prescriptive or descriptive. The assumption behind prescriptive process theories is that the designer would arrive at a better design if s/he follows the engineering design process (Finger & Dixon, 1989a). A review of prescriptive design process approaches has revealed the following key types: analytical approaches that are based on Zwicky's (1951) morphological approach; systematic transformation such as Pahl & Beitz's (1977) systematic approach and Hubka & Eder's (1988) theory of technical systems; processes that are related to the general design theory (GDT) proposed by Yoshikawa (1981); cross-functional information-exchange-based design processes such as concurrent engineering, whose roots can be traced back to the beginning of the 20th century (Smith, 1997) and popularized more recently by Takeuchi & Nonaka (1986); and decision-evolutionary optimization approaches such as evolutionary programming proposed by LaFleur (1991) (Finger & Dixon, 1989a, 1989b; Finkelstein & Finkelstein, 1983; Hatchuel, Weil, & Le Masson, 2013; Horvath, 2004; Konda, Monarch, Sargent, & Subrahmanian, 1992; Le Masson, Dorst, & Subrahmanian, 2013; Maier & Fadel, 2008; Spitas, 2011).

Previous work has generally defined the engineering design process as comprising four phases: (1) classification of the task; (2) conceptual design; (3) embodiment design; and (4) detailed design (Finger & Dixon, 1989a; Finkelstein & Finkelstein, 1983; Horvath, 2004; Hubka, 1982; Konda et al., 1992; Pahl, Beitz, Feldhusen, & Grote, 2007; Wallace & Burgess, 1995). The input of the first phase is stakeholder needs, ideas, and company strategies, which are then transformed in the engineering design process to the output of design specifications (Hubka, 1982, 1983; Hubka & Eder, 1988; Wallace & Burgess, 1995). A clear design specification is vital to a company's "triple bottom line," that is its economic, environmental, and social objectives (Dyllick & Hockerts, 2002).

New PSS development process models and tools

An encompassing definition for stakeholders is adopted in this study where any actors, human and non-human (Latour, 2005), including the environment are considered as stakeholders if they can affect or be affected by the new PSS (Freeman, 1984).

There has been a growing interest in defining a standardized process for new product/service development since the 1950s with the goal of improving new product/service success (Booz, Allen, & Hamilton, 1982). Many new product development (NPD) models recognize the importance of incorporating customer needs at the beginning of the process, through market research or lead-user involvement (e.g., Cooper, 1994; von Hippel, 1976). New service development (NSD) models from service marketing and management communities depict the employee-user interactions in service delivery, for example, in the form of the service blueprint (Shimomura, Hara, & Arai, 2009; Shostack, 1984) and description of the environment where the service is to be delivered (e.g., Gummesson, 2007). Concurrent product and service development frameworks (Hull, 2004; D. M. S. Lee, 1992; Takeuchi & Nonaka, 1986) were also developed to incorporate multiple stakeholder interests in the new product and service designs by involving different functions early in the NPD/NSD process.

Since the 2000s, new product-service system development (NPSSD) models have been proposed. Initially, the NPSSD models were based on extant NPDs and NSDs. These proposals were either product-focused or service-focused (Maussang, Zwolinski, & Brissaud, 2009) and considered stakeholder interests of the product and service portions separately, probably reflecting the fact that the product and service design activities were done separately (Meier, Roy, & Seliger, 2010). For example, proposals from the service engineering community (e.g., Sakao & Shimomura, 2007; Tomiyama, 2001) in this period focused almost entirely on target user experiences, while some considered the interests of the environment in the design process.

Since the mid-2010s, NPSSD models have been extended to include a wider set of stakeholders. For example, a PSS stakeholder identification framework for the healthcare information technology industry was developed to systematically identify stakeholders from the market and operating environment to the beneficiaries of the new product/service at the early stage of the new development process (Yip, Phaal, & Probert, 2014). Recent application of the service engineering methodology integrates the interests of both direct and indirect product and service stakeholders (Rondini, Pirola, Pezzotta, Ouertani, & Pinto, 2015). More recently, a “multi-view” framework (Trevisan & Brissaud, 2016) that has coupled some existing NPD and NSD models with one of the very first NPSSD models that tackled product and service design holistically, called the functional block diagram (FBD) method (Maussang et al., 2009) has been proposed. The FBD framework is capable of considering stakeholder interests of both the product and service portions of the PSS simultaneously.

Despite the growing number of engineering design models, recent research studies continue to recommend engineering designers consider the needs of all stakeholders along the life-cycle of a product (Bertoni, Bertoni, Panarotto, Johansson, & Larsson, 2016; Pigosso & Mcaloone, 2016), indicating an unaddressed need in PSS engineering design methods. Interestingly, while scholars in product and service development are still looking for a better model to support integration of multiple stakeholder concerns in NPSSD, well-established system engineering methodologies from the field of value-driven design (VDD) (Collopy, 1997) could potentially provide guidance (Bertoni et al., 2016).

In addition to process models, tools have been proposed to aid product and service requirement identification and prioritization. One set of tools focuses on translating stakeholder needs, which includes Kansei engineering (KE) that translates a consumer’s feelings to product and service design elements (Nagamachi, 1995) and quality function deployment (QFD) that translates customer requirements into technical requirements and allows users to indicate the relative strengths of the interactions between the requirements (Akao, 1990). Another set of tools elicits and prioritizes customer needs including the pairwise comparison decision-making process of the Analytic Hierarchy Process (AHP) and its generalized form called the Analytic Network Process (ANP) (Saaty, 1983; Saaty, 2008) and the Kano model (Sauerwein, Bailom, Matzler, & Hinterhuber, 1996) that groups product requirements into categories such as “must-be” and “attractive.” There are also multiple hybrid tools proposed to integrate the Kano model with AHP/ANP, AHP/ANP with QFD, the Kano model with QFD, or to integrate AHP/ANP, the Kano model and QFD altogether (e.g., Geng, Chu, Xue, & Zhang, 2011; Hartono, Chuan, & Peacock, 2013; J. Lee & Park, 2011; Raharjo, Brombacher, & Xie, 2008; Tontini, 2007). These hybrid tools are proposed to reduce the subjectivities when assigning weights to the relationships between the customer and technical requirements in QFD.

Another set of tools attempts to incorporate multiple stakeholder interests is Design for Environment (DFE) tools (Ramani et al., 2010). DFE is an extension of Design for Manufacturability (DFM) developed in the 1980s (Goffin, 2000). DFE tools, also referred to as eco-design tools, include life cycle assessment (LCA) tools, checklist-based tools, and tools that are based on QFD. Unfortunately, it has also been reported that DFE tools are difficult to develop as they require life cycle data to be projected to the design phase for key decisions (Ramani et al., 2010).

Among the reviewed models and tools, QFD-based tools appear to be the most robust towards supporting the incorporation of multiple stakeholder interests into the design. It correlates customer needs with technical requirements and can be extended to correlate environment needs with quality requirements (Ramani et al., 2010). In fact, QFD has inspired one of the steps in the application procedure for the PSS characterization scheme developed in this article.

System structural representation

For this article, it is of particular interest to review structural representations that not only depict the content of a PSS, but also the interactions between a PSS and its contingent environment as the environment is considered a stakeholder. The representation diagrams can be grouped into product-based, time-based, characteristics-based, and biological representation. Product-based representation (e.g., Shishko & Aster, 1995) provides a detailed breakdown of the product but leaves out customer-facing services. Time-based representation presents a process as a sequence of activities in the format of a design structure matrix (DSM) (Browning, 2001). It depicts the interfaces and relationships of the activities and can be extended to show external inputs and outputs of the process. As service is a sequence of activities performed, time-based DSM can be useful for service design, but engineering designers would need a separate structural representation such as a component-based DSM to represent the product portion of the PSS. Characteristics-based representation (e.g., Gallouj & Weinstein, 1997) maps the technical product characteristics with the service (use) characteristics and the production characteristics of a PSS based on their dependencies on one another. The DSM details the characteristics of a new PSS but does not help engineering designers to understand interactions at the element level.

Biological representation, which is an analogy to biological systems, shows the content of a PSS and its interaction with the environment. Shostack's (1982) molecular model and Hubka & Eder's (1988) organ structure both depict the intra-connectivity among the product and service elements within a PSS. However, only Hubka & Eder's (1988) organ structure depicts the connections between the PSS and its operating environment and describes a system as a "transformation organism" that is formed of different organs (function-carriers) and 'lives' in or is dependent upon an "active environment."

Literature gap

In summary, the engineering design stage of a new PSS development process has an important role in bringing valuable solutions to society. The theory of technical systems (Hubka & Eder, 1988) has the potential to help engineering designers to visualize interactions within the new PSS between the new PSS and its stakeholders including the environment that it is to operate in. Although some interesting design process models and tools have been proposed, those taking multiple stakeholder interests into consideration when generating design specifications are far and few between.

Methodology

This research study was exploratory in nature with the aim to contribute to the theory and practice of the "how" of PSS engineering design. The objective of the study was to first define a PSS characterization scheme that is useful for PSS engineering design and then apply the scheme to new PSS ideas in order to find out how it impacts design specifications.

In the first part, the research design of multiple cases with a single unit of analysis was chosen (Yin, 1994) in order to identify suitable variables to formulate the PSS characterization scheme for engineering design. The unit of analysis was defined as an ongoing or recently completed new product, service, or PSS development project. This study intends to contribute to the theoretical perspectives in the engineering design process using case study research (Eisenhardt, 1989). As a result, the study did not begin with a definite theoretical proposition but only some "potentially important variables" from extant literature (Eisenhardt, 1989, p. 536). Variables in this study are characteristics that are *useful* for describing a PSS for the purpose of engineering design.

Following the logic of theoretical sampling, cases were targeted to replicate emergent findings and to extend the relationships among variables (Eisenhardt & Graebner, 2007; Yin, 1994). The number of cases was therefore not pre-determined. Data collection and analysis were designed to overlap in order to allow for adjustment of the data collection instruments, if initial reflections indicated such needs. This method supports the emergence of relevant variables (Eisenhardt, 1989) for theory building.

The primary data source in this study is case study interviews, and the secondary data source is publicly available documents about the new PSSs discussed in the case study interviews. The primary data collection instrument that was adjusted to support the emergences of relevant variables is the interview protocol. Each revision of interview protocol marked a new iteration; there was one pilot study and three iterations of case study. Within-case analysis was performed after each case study, and cross-case analysis was performed when common themes began to emerge from the within-case analyses and sufficient data had been collected. Both within-case and cross-case analyses utilize data analysis frameworks designed for this study, which will be described in the next section. The emerging variables from cross-case analysis informed the case selection strategy.

As an example, initially the proportion of product and service content in a PSS was explored as a potentially important variable to describe PSS for engineering design, and development projects of PSS of different proportion of product and service content were targeted. After cross-case analyses, the types and degrees of connectivity within the PSS and with its contingent environment emerged to be more useful. Therefore, after the first iteration of case studies, the type of PSS connectivity, instead of product and service mix, was used to select cases. The case study ended when the numbers of new relevant variables reduced between iterations, that is, when the sampling saturation point was reached.

To further explain the sampling saturation point, the number of variables emerged in each iteration of case studies is detailed here. In this research, the pilot study started with three potential variables from literature related to stakeholders (1.1 types of stakeholders; 1.2 levels of stakeholder groupings; 1.3 dimensions – e.g., internal or external of stakeholders). These three variables were replaced with seventeen other potential variables that emerged from the pilot study in the first iteration case study. In the second iteration, two new potential variables were identified and two that were introduced in the first iteration were found to be not useful and were dropped from the interview protocol. In the third iteration, only two new potential variables were identified. Eight variables and one potential variable introduced in the first and second iteration were found to be not useful in characterizing PSS for engineering design.

The second part of this article examines how the new way of characterizing PSS impacts design specifications in different contexts. Action research was an appropriate method to achieve this aim. The knowledge generated from these workshops was bounded by context (Reason & Bradbury, 2001; Susman & Evered, 1978). Through planned actions in the format of workshops, the researchers and participants tested out the conjecture that the proposed PSS characterization scheme may clarify design specifications. The outcome of each workshop was evaluated through reflection. Seven workshops with practitioners who were involved in the development of new PSS ideas in five industries were completed.

Data Collection, Analysis and Findings

Part I – Case Study

Data collection and analysis

The case study was designed to identify variables that characterize PSS for engineering design. Exhibit 2 shows the details of the eleven new development projects, involving twenty-five new PSSs from nine companies participated in the case study, and the roles and experience of the interviewees. In each case, at least one development team member was interviewed. Most interviews were carried out face-to-face or via an Internet phone application, where the interview protocol was used to guide discussions and note-taking. A total of 1534 minutes of interviews were recorded for analysis.

Insert Exhibit 2 here

Within-case analysis was carried out for each case study as soon as all candidates from the case were interviewed. The analysis was done via a framework prepared in Microsoft Excel, containing the factors explored in the interviews (see Exhibit 3). Cross-case analysis was performed when common themes began to emerge from the within-case analyses and once sufficient data had been collected. The case studies completed before a cross-case analysis were grouped together as one case study iteration. A change in the interview protocol led to a new iteration of case study including data collection and within-case analyses. When changes in priority of the potential variables were deemed necessary, the within-case analyses were subsequently redone. When new potential variables were added to the revised interview protocol, new data were collected.

Insert Exhibit 3 here

The cross-case analysis consisted of two steps. First, the information collected for each potential variable from the completed cases was compared. Second, the data was grouped to examine any emerging patterns. Different ways of data grouping were tried. These included grouping cases that display the same results for one potential variable, a combination of potential variables, or a combination of other factors that were not considered as potential variables. An example of the framework used for cross-case analysis for one potential variable is shown in Exhibit 4.

Insert Exhibit 4

Findings

As part of the data analysis process, potential variables were added, modified, combined, or dropped throughout the course of data collection process in search of those that could be useful in describing a PSS for the purpose of engineering design. Exhibit 5 shows the nineteen potential variables explored in the three iterations of case study. The variables resulting from the third iteration of case studies that were most relevant to describe PSS for the purpose of engineering design were: (1) customer perceived value; (2) connectivity number; (3) type and degree of connectivity; and (4) PSS configuration type. These four resulting variables, together forming the PSS characterization scheme, came from the variables 2.1 "Dimension of PSS classification," 2.2 "Characteristics of the PSS configuration," and 2.5 "Types of relationships" as shown in Exhibit 5. The four variables, or four PSS characteristics, are described next.

Insert Exhibit 5 here

<u>The PSS characterization scheme</u>

The first characteristic in the proposed PSS characterization scheme, customer perceived value level, is the value that the target customers perceive they can potentially generate from the new PSS. The higher the value level, the more desirable the PSS is perceived to be.

The second characteristic, connectivity number, is the number of interactions between the new and existing elements of a PSS or the environment it is intended to be used in. This number shows the level of attention that is above routine design effort a design team needs to give to the new PSS design. Only the relationships between 'new' and 'existing' elements are counted. A higher weight is applied to the number of 'new impacting existing' relationships, because introducing a new element that will impact an existing element that has been functioning well may warrant special attention from the design team. A discount factor is applied to the number of ‘new impacting new’ and ‘existing impacting existing’ relationships. This is because the connectivity number is to represent the additional development effort required as a result of the presence of new/existing relationships. The higher the connectivity number, the more complex the development potentially is with regards to its relationships with other systems and the environment.

The third characteristic, type and degree of connectivity, is related to the connectivity number, and it provides more information about the nature of the relationships among the new and existing elements of a PSS. Connectivity concerning product elements is described as data/physical connectivity. This is because these elements connect either physically or at a data exchange level. Connectivity concerning service elements is described as process connectivity. This is because services are actions and the connections among services mean that series of actions or processes are being connected. For each type, there can be three degrees of connectivity: ‘Independent’ when there is no relationship between the new and existing elements; ‘Linked’ when one or more new elements depend(s) on the existing element(s); and ‘Incorporated’ when one or more new elements impact(s) the existing element(s).

The fourth characteristic, PSS configuration type, represents the structure of a PSS in terms of how the product and service portions interact with one another and what the main role of product/service is in the PSS. These are five-mirroring pairs of abstract structural representations (see Exhibit 6). Group A has either service elements being encased within product elements or vice versa, named “Encased Service” and “Encased Product” respectively. Group B has a service element that caused a “bolt-on” configuration of the PSS or vice versa, named “Deforming Service” and “Deformed Product” respectively. Group C has service elements in between product elements or vice versa, named “Sandwiched Service” and “Sandwiched Product” respectively. Group D has service elements being the basic input to the product elements or vice versa, named “Static Service” and “Static Product” respectively. Group E has only service or product elements, named “No Service” and “No Product” respectively. Hypothetical examples are provided to explain these five pairs of PSS configuration type in Exhibit 6.

Insert Exhibit 6 here

Part II – Action Research

Data collection and analysis

Part II of the study examines how the proposed PSS characterization scheme impacts design specifications in different contexts. To apply the PSS characterization scheme and collect data about the influences the scheme may have on design specifications, an application procedure that consists of four mandatory steps and an optional step was designed (see Exhibit 7). Similar to Part I, the number of workshops was not planned in advance but strategically selected in order to achieve the aim of examining the influence of the proposed scheme on design specifications in different contexts. The researchers targeted companies with new development projects at the engineering design phase from different industries and companies. After each workshop, the outcome was discussed jointly with the participants, and the researchers reflected and planned actions for testing in subsequent workshops.

Insert Exhibit 7 here

Different means of recruiting case companies were used including using the university’s newsletter that industrial companies subscribed to and through the researchers’ professional networks. The candidate companies were informed that in order to qualify for the workshop, they must have a new PSS idea at a stage that was beyond initial market research but before detailed design had begun and that all participants must be directly involved in the new development. The participants would need to be available for at least two hours for a simple PSS development or four hours for a more complex PSS. In return, the companies would learn more about the new PSS they were developing. A total of nine action research workshops were conducted, but two of them ran out of time and could not complete all four mandatory steps of the application procedure. These two workshops were excluded from the study. The details of the seven action research workshops in five industries are provided in Exhibit 8.

Insert Exhibit 8 here

As explained in the methodology section, action research is a method that researchers and participants test out a theory through planned actions in the format of workshops, and the outcome is evaluated through reflection. In order to minimize the effect of facilitation style and effectiveness on the workshop on the data collection process, the same facilitator was used for all workshops, and the facilitator kept her facilitation style consistent. For example, she allowed discussions to run as long as they were about the PSS design, she proactively engaged quieter participants to share their opinions, and she used the agenda to manage time but gave flexibility to the decomposition and representation steps in order to arrive at some insights. Audio recordings (thirty-nine hours) and photos of drawings and diagrams output during the workshops were created. The facilitator recorded her learnings from the workshop immediately after each workshop, as the facilitation and observation happened simultaneously.

Findings

From the discussions with the participants and the observations and reflections made in the seven workshops, three impacts of the PSS characterization scheme on design specifications emerged.

Impact 1: Improve clarity of product and service feature requirements

The first impact is about gaining more clarity of the internal structure and relationships among the elements within the PSS. Participants of all seven workshops reported that they realized something more about the relationships among the products and services within the PSS. The PSS characteristics that were teased out during the workshops triggered lively discussions among the development team members, which aligned team member's understanding of what the new PSS was about, which part of the development was more important, and which part needed to be developed before the others.

Impact 2: Improve clarity of PSS contingent environmental conditions

The second impact is about the operating environment of the PSS. Participants of six of the seven workshops reported that they realized more about how the operating environment would impact on the PSS and how the PSS could impact the operating environment. This realization led to discussions on which department/function in the company to further understand the impact on the operating environment in order to find out if any additional requirements on the PSS design would be needed. The PSS characterization scheme surfaced the otherwise hidden need of the environmental stakeholder and allowed it to be addressed in the engineering design phase of the PSS development process.

Impact 3: Inform the relative complexity of PSS development

The third impact is about the complexity of a PSS development and how to potentially reduce the complexity by modifying the design. Participants of five out of seven workshops reported that they learned more about the relative complexity of the PSS design. Participants of three of the seven workshops also expressed that the workshop facilitated holistic conversations, where technical feasibility of an engineering design was debated alongside the potential customer value of the design.

Other findings

Apart from the three impacts on the clarity of design specification summarized above, there were other findings that may be useful for other companies applying the PSS characterization scheme to analyze PSS in the future. Participants of five of the seven workshops reported that the workshop had informed, clarified, and built their business strategy and business model. One company had also commented on the potential use of some of the diagrams output from the workshop to facilitate internal strategy communications.

In conclusion, the PSS characterization scheme was found to be capable of improving the clarity of all three aspects of a design specification: product and service features, stakeholder involvement in the engineering design process, and contingent environmental factors. In particular, the two PSS characteristics, connectivity number and the configuration type, provided an indication of the relative complexity of a new development. The application procedure allowed the participants to simulate how to reduce the level of complexity of the development. By identifying the product or service element(s) of the PSS design that caused the complexity, new development team members could discuss design changes to reduce complexity without scarifying its potential value to customers as indicated by the PSS characteristic called customer perceived value level.

Contributions

The Part I case study allowed the PSS characterization scheme for engineering design to emerge. The application procedure for this characterization scheme used in the Part II action research workshop showed that the PSS characterization scheme was capable of clarifying the three aspects of design specification: product and service features, stakeholder involvement, and contingent environmental factors. This study addressed the key literature gaps identified: (1) PSS development process models that incorporate multiple stakeholder interests without being product-biased or service-biased and (2) structural representations that depict a PSS's internal relationships among the product and service portions as well as its linkages to the operating environment. The contributions from this research are inspired by relevant concepts from the literature of engineering, management, and sociology such as Hubka and Eder (1988), Shostack (1984), Gummesson (2007), and Latour (2005) and are grounded in the case studies. It is a novel way to characterize PSSs for engineering design and contributes to the literature of PSS engineering design methods.

Implications for Engineering Managers

The new product/service/PSS development process is an important topic in engineering management. This study has extended this on-going discussion from NPD to NPSSD. The proposed PSS characterization scheme, when applied to new PSS ideas, facilitates the development team to build multiple stakeholder interests into design specifications. Development teams in the case companies have benefited from the proposed scheme to clarify the required features, stakeholder involvement, and the contingent environmental conditions of their new PSS ideas. The application procedure developed to analyze new PSS ideas for the four characteristics in the proposed PSS characterization scheme, namely the customer perceived value level, connectivity number, type and degree of connectivity, and PSS configuration type, has shown to be capable in clarifying design specifications before companies invest in the detailed design stage. The customer perceived value level helps development teams to evaluate new PSS ideas in the context of the complexity that arises from the interrelationships within a PSS and between the new PSS and other systems and conditions in its contingent environment in conjunction with the potential value customers/users could generate from them. The process of identifying the connectivity number, the type and degree of connectivity, and the PSS configuration type also encourages the development teams to incorporate contingent environmental conditions into design specifications, which are often left out in the early stage of the NPSSD process. This application procedure has the potential to be further developed into a business application to support the PSS engineering design process.

Conclusions

The engineering design process is important. Through this process, stakeholder needs and desires are transformed into design specifications, which manufacturers and service providers develop and produce as new offerings. When customers use the PSSs they want, value is realized. A clear design specification is crucial to achieve the value potential of a new PSS. Moreover, a non-product-biased or non-service-biased method for analyzing PSSs could help generate unambiguous design specifications. This article summarizes a study that contributes to the new product/service development process and provides a novel way to incorporate multiple stakeholder interests into the design specifications of new product-service systems.

As with all studies, there are limitations to the findings. First of all, the PSS characteristics that emerged were based on individual's opinions collected through interviews. Although attention was paid to include more than one stakeholder in each case study where possible, the information obtained cannot be considered as a full picture of the development projects. Another limitation is that participants of failed development projects may not have volunteered to discuss their project experiences. Indeed, one contact mentioned a failed project experience and had declined to discuss it any further about this study. Therefore, all the collected data came from successful new PSS development projects or projects that the company's management evaluated as satisfactory enough to proceed with developing. As a result, the proposed characteristics may only apply to successful PSSs. Furthermore, the four characteristics are identified from healthcare PSSs. Although applied to four other industries in Part II of the study, its application may be limited to the five industries involved in the study.

Further studies with PSSs from companies of different industries, sizes, and country of operation will strengthen the findings of this study. With more data, the definitions of the four PSS characteristics for engineering design can be refined and the procedure used for applying the PSS characterization scheme can be systematized as a business tool to support the early stage of the new PSS development process.

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Biography

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Man Hang Yip is an Academic Collaborator at the Centre for Technology Management within the Institute for Manufacturing, at the University of Cambridge Engineering Department. She obtained her PhD in 2015 with the dissertation titled "Healthcare product-service system characterisation - implications for design". She has 20 years of professional experience in industry in operations excellence and service system design. Her research interest includes system design, use of graphical representations, and development of practical management tools.

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Exhibit 1 Definitions adopted in this study

Terms	Definitions adopted in this study	Comments and references
I. Product / Service / Product-service system		
Product	A product can exist independently of its owners and preserves its identity through time. By this definition, a product can be intangible. Examples are software, a sound track and a digital book.	A view proposed for economics (Hill, 1999).
Service	A service cannot be stocked and is constrained by the need to have both producer and consumer interacting at the same time.	A view proposed for economics (Hill, 1999). This is different from the frequently referenced service characteristics of IHIP (intangible, heterogeneous, inseparable and perishable) (Gummesson, 2007; Vargo & Lusch, 2004).
Product-service system (PSS)	A combination of products and services that together fulfill customers' needs. This combination may consist of only products, only services or both products and services.	Although PSS is a way for manufacturers to reduce potential environmental impact, this definition is from policy (Goedkoop et al., 1999) and marketing literature (Bell, 1986; Rathmell, 1966; Shostack, 1977), as it explains what a PSS is from a customer's perspective.
II. Stakeholders and their interests		
Stakeholders	Any actors, both human and non-human, that can affect or be affected by the new product/service/product-service system.	Extended from Freeman's definition for business and policy (Freeman, 1984), and incorporating the social science theory of Actor Network Theory (Latour, 2005) where actors can be both human and non-human.
Multiple stakeholders' interests	Include objectives required or encouraged by institutional bodies in society (e.g., government, regulatory bodies), constraints and requirements imposed by the contingent environment, as well as the people producing, purchasing and using the new products/services/product-service system.	This follows from the definition of 'stakeholder' provided in this table.
III. Design and development		
Development process	The starting point of a development process is the needs or desires of stakeholders, and the ending point is the market launch of a new offering that can be a product, a service, or a PSS.	This definition is adopted from marketing and engineering literature (Cooper, 2008; Kindström & Kowalkowski, 2009).
Engineering design process	A prescriptive process performed by human and aided by technical means, where requirements are transformed into descriptions of technical systems. The input of the engineering design process is information in the form of stakeholders' needs or desires, and the output is information in the form of design specifications. In this study, the engineering design process can be understood as the early stage of new product/service/PSS development process.	The engineering design process theories can be classified as prescriptive or descriptive theories (Finger & Dixon, 1989a; Konda et al., 1992). The definition adopted in this study is prescriptive, which is from engineering and design literature (Hubka & Eder, 1988; Wallace & Burgess, 1995).
Design specifications	A design specification is the output of the engineering design process, where the design task is clarified. In this study, a design specification includes the consideration of three aspects: (1) product and service features; (2) stakeholder involvement; and (3) conditions of the relevant environmental factors.	This definition is based on engineering and design literature (Konda et al., 1992; Pahl et al., 2007; Wallace & Burgess, 1995), and is extended to include stakeholder involvement and environmental contingent factors as part of the specification.

Exhibit 2 List of case studies conducted in Part I

Case Study Iteration number in bracket, name of the case / reference number of PSS studied	**Industry sector**	**Company: size, location** **Customer: target market[1]**	**Interviewees: title, role(s) in the PSS development project, years of experience**
(1) Digital / i, ii	Healthcare informatics	Small, Australia, UK	Informant 1: Technical director (technical and management, >25yrs) Informant 2: Senior consultant (service delivery, >15yrs)
(1) Signal / iii, iv, v	Healthcare informatics	*Same as Case Digital*	Informant 1 (same as Informant 1 in *Case Digital*): Technical director (technical and management, >20yrs) Informant 2: Principal (commercial and management, >30yrs)
(1) FastReport / vi, vii, viii	Healthcare informatics	Medium, Sweden, UK and Australia	Informant 1: Product manager (technical and service delivery, >20yrs) Informant 2: International business development manager (commercial, >15yrs) Informant 3: Head of development (technical, >15yrs)
(1) BedManagement / ix, x, xi	Hospital advisory	Large, USA, USA	Informant 1: Senior solution consultant (technical, >20yrs) Informant 2: Consulting manager (technical and service delivery, >15yrs)
(1) ProactSvr / xii	Medical device	Large, USA, USA	Informant 1: Technical service director (technical and management, >30yrs) Informant 2: Service marketing leader (commercial, >20yrs)
(2) PredictSvr / xiii, xiv	Medical device	Large, France, Europe	Informant 1: Service life cycle manager (commercial, >15yrs) Informant 2: Service marketing manager (commercial, >30yrs) Informant 3: Service project leader / engineering (technical, >5yrs)
(2) eLearnHospital / xv, xvi	Training for healthcare professionals	Small, Finland, Finland	Informant 1: Consultant (management, technical, and service delivery, >10yrs)
(2) eLearnCharity / xvii	Training for patient-facing workers	*Same as Case eLearnHospital*	Informant 1 (same as Informant 1 in *Case eLearnHospital*): Consultant (management, technical, and service delivery, >10yrs)
(2) Stent / xviii	Medical implant	Small, UK, UK	Informant 1: CEO (management, >30yrs)
(2) GroupTraining / xix, xx, xxi, xxii	Fitness	Large, USA, International	Informant 1: Director of product management (commercial, >10yrs) Informant 2: Business development manager (commercial, >15yrs)
(3) Biomechanics / xxiii, xxiv, xxv	Fitness	Small, UK, UK	Informant 1: Founder and personal trainer (management, technical, and service delivery, >15yrs)

Note[1]: Company size is based on the number of employees; company location is where the development team members are mainly located; target market is the target market for the PSS being discussed.

Exhibit 3 Framework used for within-case analysis (an example)

Case Name	**Date of interviews**		
Case FastReport	12-Apr-12 **Interviewee A**	11-May-12 **Interviewee B**	29-May-12 **Interviewee C**
Type of PSS	A new product developed and implemented for the users in the hospitals	A solution that helps the efficiency of reporting	
Type of Environment	Mainly radiology department of hospitals	Radiology and out patients services in hospitals	
Factors explored in the interview			
Interviewee Role	Product Manager	Commercial	Technical - Product Developer
Interviewee involvement duration	Involved throughout the whole development project	Involved from the beginning to the end of the project	Involved pretty much throughout the project
Development project start	2007/8	2007	2007
Development project pass early stage	The product is always evolving, there is always development taking place. There is no set date. It is on-going, organic, you need to re-plan things, or start from stretch. It is an on-going relationship rather than the technology itself.	The solution was in the early stage of the development in the early/middle of 2010, and the hospital decided to pilot the solution in 2010. Now the solution has been launched, and has been used in other markets.	Can't give an exact date, but it was about a year from the start. (00:05:14) "Because we do two things at the same time. We incorporated the new speech technology from *PRODUCT COMMERCIAL NAME*. And we implemented the *CLIENT's SYSTEM NAME* at the same time. For each iteration, the.. ah we can do this, we want to change this part, we had a lot of iterations before we had a working solution for them. So, it is difficult to pinpoint one particular date."

Exhibit 4 Example framework used for cross-case analysis

Step 1: Analyze one potential variable at a time	**Relevant findings from each case**				
	Case Digital	Case Signal	Case FastReport	Case BedManagement	Case ProactSvr
V1.1 Types of stakeholder	Being involved (having an input to) vs Having an interest in the development activities vs impacted by	Main / Supporting (Main: Nurses, Doctors, Patients; Supporting: IT)	Company / Vendors / Partners / Customers / End-users	Customer (Hospital) / Company's product (Technology) / Company's service (Advisory) / Company's Development Process Development (Solution development) / Company's GM	Customer / Field Service / Company's back office (HQ) people
	Immediate hospital groups (those who input, or use output) / Support (IT, PM, Change Mgmt) / Outside (Authority : DoH or Patient)	Have an input and interest, no input, impacted by (e.g. patients)	Users / Customer management / Customer's IT informatics / Patients / Developers / Company's owners / Company's sales	Hospital Management / Hospital Deliverer (front-line)/ Process triggered (Doctors) / Receivers (Patients, families, other facilities)	Customer / Company's Commercial / Company's engineering / Company's service development / Company's field service
		Clinical/Medical (Immediate to the PSS), Hospital executive / People who adopt and support of ICT and its integration / External interests groups / External domain expertise			
Step 2: Elicit potential dimension for each variable	**Mark with "X" where a dimension was mentioned by at least one interviewee**				
Dimension for V1.1	Case Digital	Case Signal	Case FastReport	Case BedManagement	Case ProactSvr
Customers' end users	X	X	X	X	X
Company's development	X	X	X	X	X
Customer's Management	X	X	X	X	X
Company's Management	X	X	X	X	X
Customer's IT support	X	X	X		X
Company's service delivery					X
Patients	X	X	X		X

Exhibit 5 Convergence of relevant variables

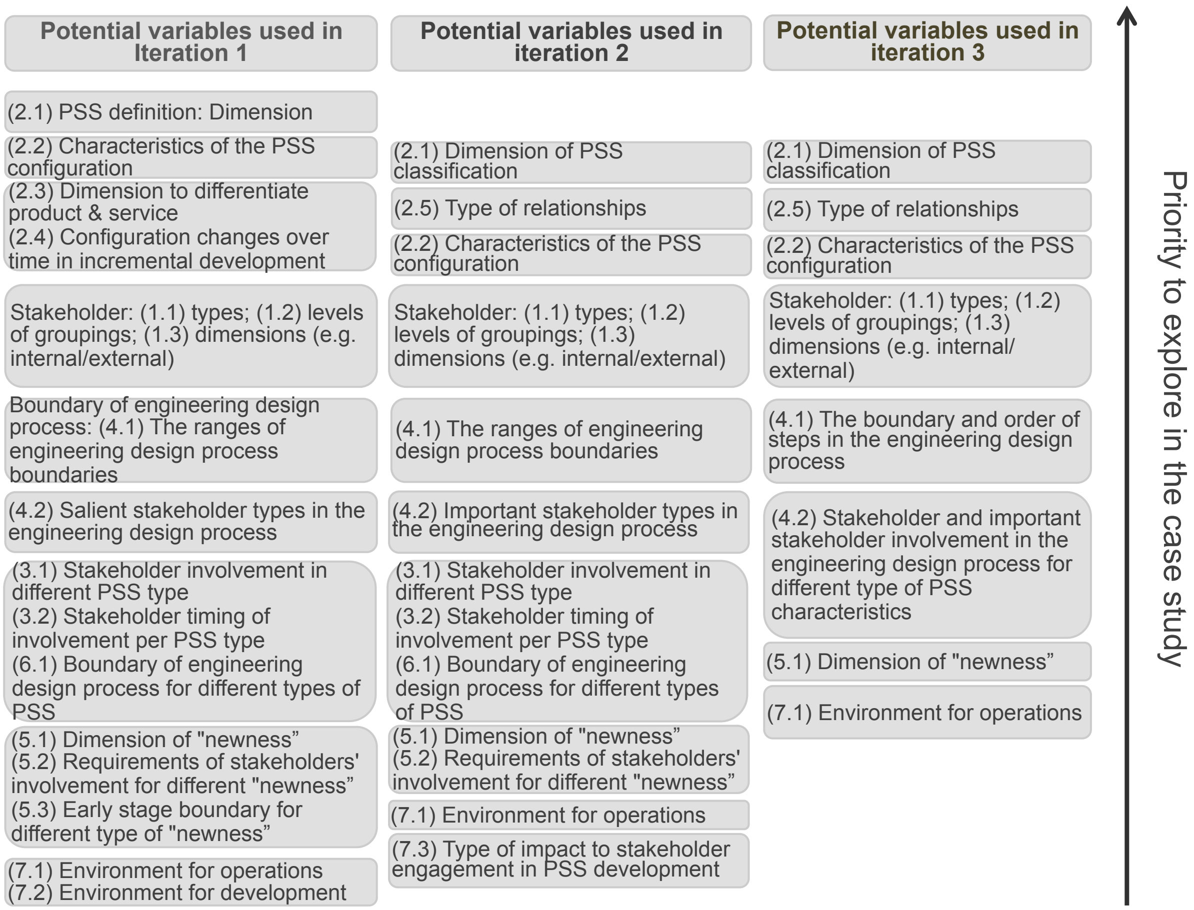


Exhibit 6 PSS configuration types (adapted from Yip et al., 2015)

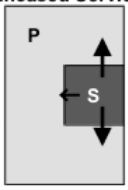
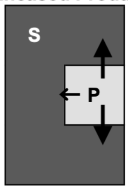
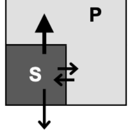
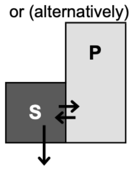
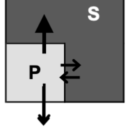
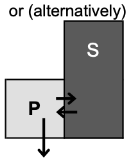
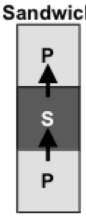
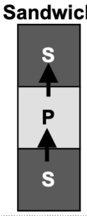
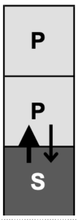
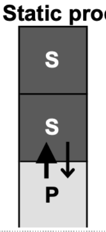
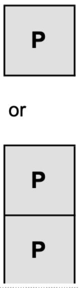
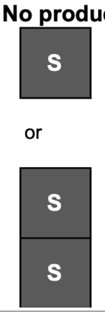
PSS configuration types emerged from the case studies	Key features	Hypothetical examples
A1 - Encased Service 	The service is most likely a basic operation The service impacts products above and below The service may impact product of the same level	A famous running coach who is offering a tailored package (higher level product) of running technique leaflets previously published (lower level products) by analyzing the questions (service) runners have asked her in her coaching career and developing a map of runners' challenges to running techniques (mid-level product). The running technique leaflets (lower level products) are revised according to the insights gain from the analysis (service).
A2 - Encased Product 	The product most likely provides a basic function The product impacts services above and below The product may impact service of the same level	A running coach has a chat with a group of beginner runners in the running club (lower level service) and has found out that they do not understand some dynamic warm-up exercises. She then gives the runners some instruction sheets (products) and asks the runners to follow the sheets with her supervising (mid-level service) on the side, and continues to address other concerns that the runners have. This helps the coach to improve her runners' overall running experience (higher level service).
B1 - Deforming service  or (alternatively) 	The service causes the "bolt-on" configuration The service impacts on the product above or interacts with the product at the same level (the top diagram) The service can be a standalone service or an external operation (the bottom diagram)	[this example is represented by the top diagram] A running shoe retailer that provides gait analysis (service that can be offered independently), and also sells the gait analysis (service) with the specialized insoles (higher level product) for running shoes (lower level product).
B2 - Deforming product  or (alternatively) 	The product causes the "bolt-on" configuration The product impacts on the service above or interacts with the service at the same level (the top diagram) The product is a standalone product or an external product (the bottom diagram)	[this example is represented by the bottom diagram] A running coach who uses gait analysis software (product that is an external product) to help her to provide a more in-depth analysis of her client's running technique (service at the same level). She then designs new exercises that aim at improving her client's running technique (higher level service).
C1 - Sandwiched service 	The product at the top level is an additional offering The product at the top level does not impact service in the middle The product at the lower level is fundamental to the service	A running technique improvement video (product) that is produced by filming a running coach correcting the techniques of different runners (service) in agility improvement exercises involving running around sports marker cones (lower level product).
C2 - Sandwiched product 	The service at the top level is a customer facing service The product in the middle is a production aid to the service on top The service at the lower level is fundamental to the product	A running coach who provides running technique improvement advice (service) uses some specialized video recording devices (product) to record how her clients run. These devices are rented (lower level service) from a photography equipment company.

Exhibit 6 The PSS configuration types *(continued)*

D1 - Static service 	The product elements are using the service mostly as a static input to the product	A forum for amateur marathon runners to exchange tips and tactics on improving running abilities (lower level service), gives certificates of different levels of expertise (higher level product) based on users' level of contribution.
D2 - Static product 	The service elements need customer involvement in the production The service elements are using the product mostly as a static input to produce the service	A workshop for amateur marathon runners preparing for the London Marathon (higher level service) has its content (lower level product) tailored based on the questions asked by the workshop participants.
E1 - No service 	The product element(s) are standalone product(s)	A recording of the 4x100m relay race in the Summer Olympic Games.
E2 - No product 	The service element(s) are standalone service(s)	Watching a 4x100m relay race at the event venue.

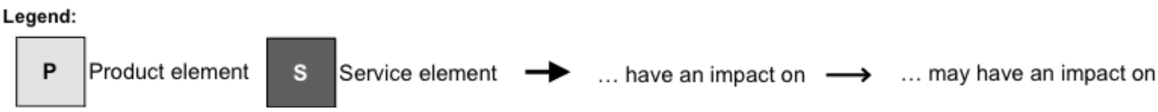


Exhibit 7 PSS characterization scheme application procedure

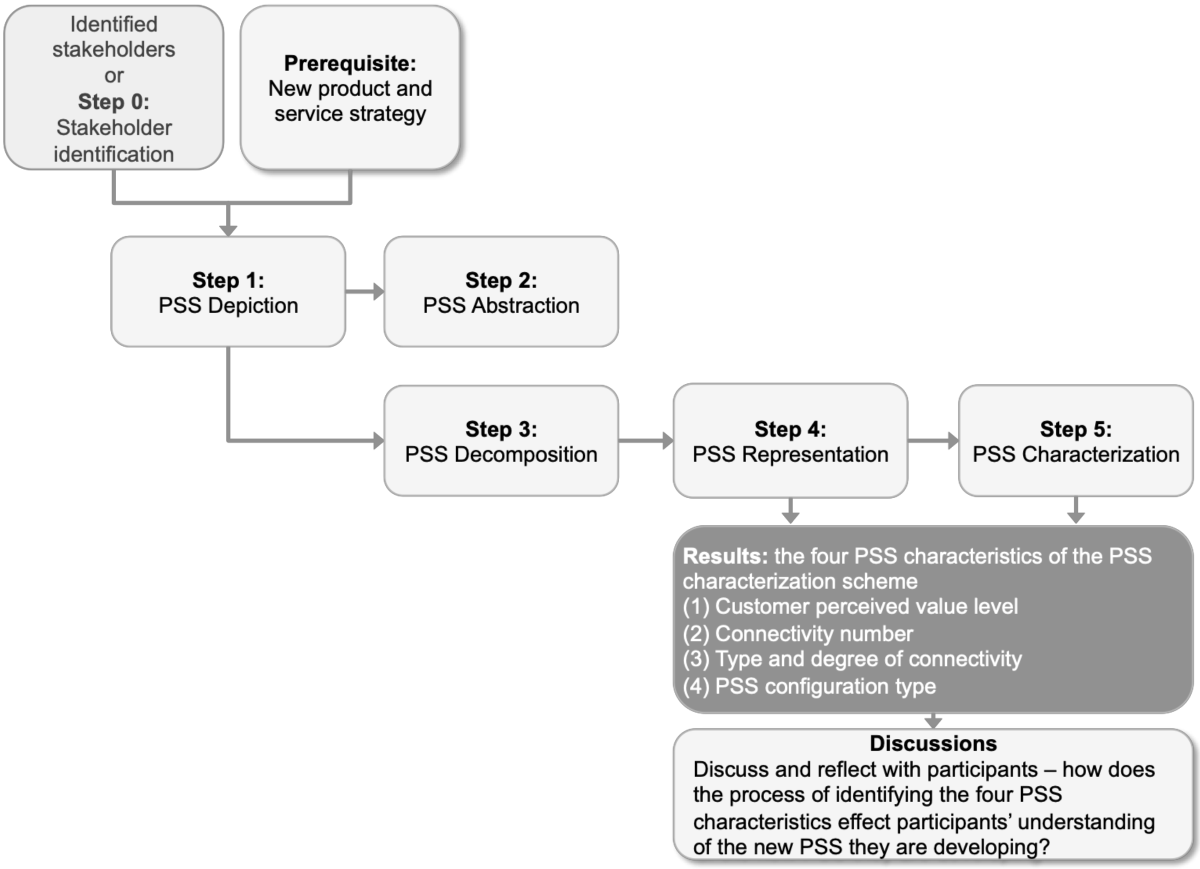


Exhibit 8 List of workshops conducted in Part II

Workshop Reference	Industry	About the company and the participants	Workshop date and duration (in hours)
Q	Defense	A large multinational defense company with headquarter in the United States of America. Two participants from the new development team, with deep understanding of the company's technical capability, and management strategy and market knowledge.	Date: Jun 26, 2013 Duration: 7.5 hours
R	Healthcare - fitness	An entrepreneur based in the United Kingdom who offers fitness services, usually in a gym environment. One participant (the owner), focusing on his technical design, sales & marketing and service delivery expertise for this new PSS.	Date: Oct 27, 2013 Duration: 4 hours
S	Environmental protection	A small to medium size company in the environmental protection sector with headquarter in Estonia. Seven participants, with knowledge in management, operations, sales & marketing, R&D, logistics, quality, new product project management	Date: Nov 08, 2013 Duration: 5.5 hours
T	Healthcare – mental health	A small psychology counselling service provider based in Hong Kong. One participant with solution design, sales and service delivery experience.	Date: Nov 26, 2013 Duration: 2.5 hours
U	Financial investment	A multinational financial investment firm with headquarter in the United Kingdom. One participant with technical development experience, in particular East Asian based financial products development.	Date: Dec 01, 2013 Duration: 2 hours
V	Executive education	A small executive education firm based in the United Kingdom. Four participants including the course designer, knowledge domain expert, and course logistics design and delivery.	Date: Jan 31, 2014 and Feb 28, 2014 Duration: 2.5 hours and 3 hours
W	Healthcare – medical device	A large multinational medical device company with head quarter in the United States of America. The development was in the United Kingdom for the United Kingdom market. Six participants, including a pathologist, a nurse, an a communication officer in a public hospital in the United Kingdom, and two participants from the medical device company with experience in research and development in medical devices and sales.	Date: Dec 10, 2013 and May 19, 2014 Duration: 6 hours and 4 hours